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Residential Greenhouse Gas Emissions

Special Studies, April 30, 2007

By Paul Emrath, PhD and Helen Fei Liu, PhD.

Greenhouse gases are chemicals that, when released into the atmosphere, have the potential to cause global warming. Global warming has received a lot of attention lately. Part of this attention has fallen upon the housing sector and the role it plays in generating greenhouse gases.

The largest components of greenhouse gases generated by human activity over the course of a year result from energy that is produced and consumed. Because of this, the Energy Policy Act of 1992 assigned much of the responsibility for tracking greenhouse gas emissions to the Energy Information Administration (EIA), the statistical agency housed inside the U.S. Department of Energy.

This article summarizes information from standard EIA reports on greenhouse gases. The article also analyzes data compiled by EIA on household energy consumption, in order to better understand the role housing—in particular new housing—plays in emitting greenhouse gases. The topics covered include the relationship between greenhouse gases and residential energy use, the distinction between annual energy use and "life cycle assessments," the relative impacts of new and older homes, and the role household behavior plays independent of the characteristics of the house itself.

Conclusions drawn include the following:

- The amount of greenhouse gases emitted from a residential structure during a typical year of its life is primarily a function of how much energy it consumes.
- Residential energy consumption is the result of many factors, particularly how it is constructed and how it is used.
- New homes only account for a small share of the total housing inventory, and likewise a small share of annual energy consumption.
- Production and transmission of the electricity for homes constitutes a significant portion of residential greenhouse gas emissions.
- Household behavior, such has how long lights are left on, may have as great an impact on residential electricity consumption as the number of built-in appliances or other amenities provided by home builders.

Greenhouse Gases and Energy Use

The greenhouse gases tracked by EIA include carbon dioxide (CO2), methane, nitrous oxide, various hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. That's quite a list, but CO2 accounts for the lion's share, so for some purposes an analysis based only on CO2 emissions is considered adequate. [1]

Greenhouse gases are emitted by natural sources as well as by human activities. For example, CO2 is emitted when an animal exhales or water evaporates from the ocean. In fact, the Intergovernmental Panel on Climate Change (IPCC) estimated that 97 percent of CO2 emissions worldwide in the 1990s came from natural sources. [2] However, the additional three percent that resulted from human activity was enough to push emissions above the capacity of natural processes (such as photosynthesis) to absorb them. It is in this sense that human activity is responsible for the rising concentrations of CO2 observed in the atmosphere.

EIA usually expresses emissions in millions of metric tons (MMT). EIA's preliminary estimates for 2005 include 6,009 MMT of CO_2, compared to only 27 MMT for methane and 1 MMT for nitrous oxide (the next two largest components of total greenhouse gas emissions).

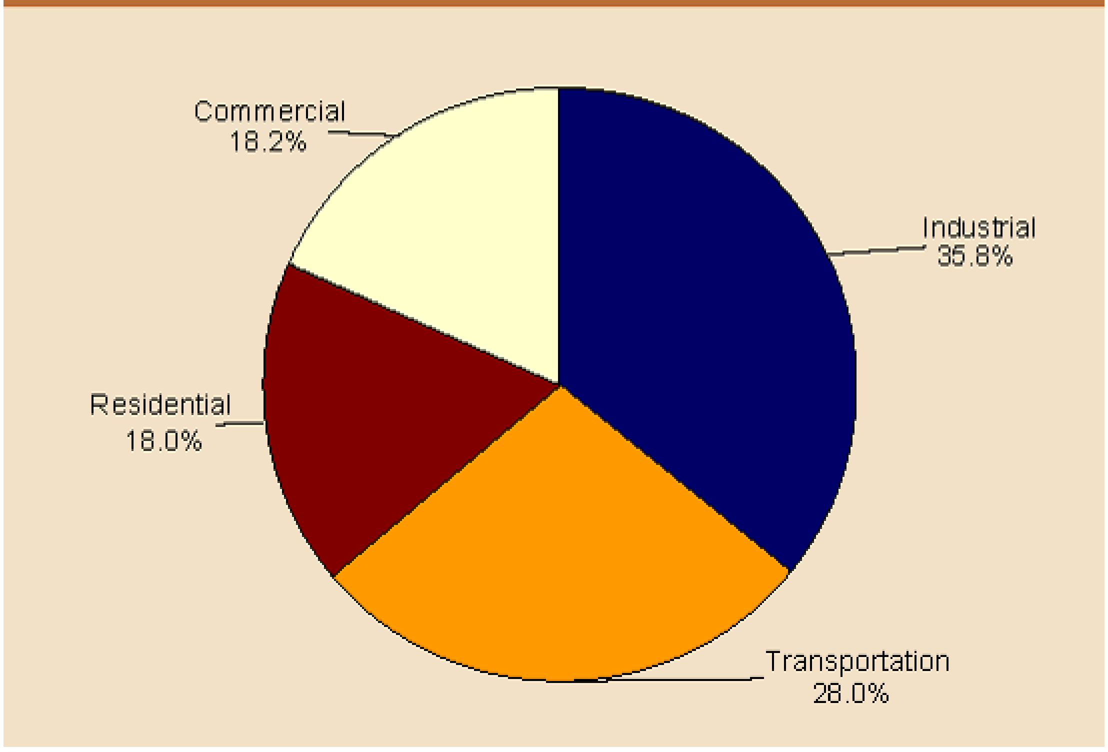
Although CO_2 has a greater impact on global warming than other greenhouse gases, the difference is not quite as lopsided as the above numbers suggest. Non- CO_2 greenhouse gases have much greater "global warming potentials" per metric ton. For example, according to the most recent IPCC assessment, a metric ton of methane has 23 times the global warming potential of a metric ton of CO_2. For many greenhouse gases the ratio is over 1,000 to 1. [3]

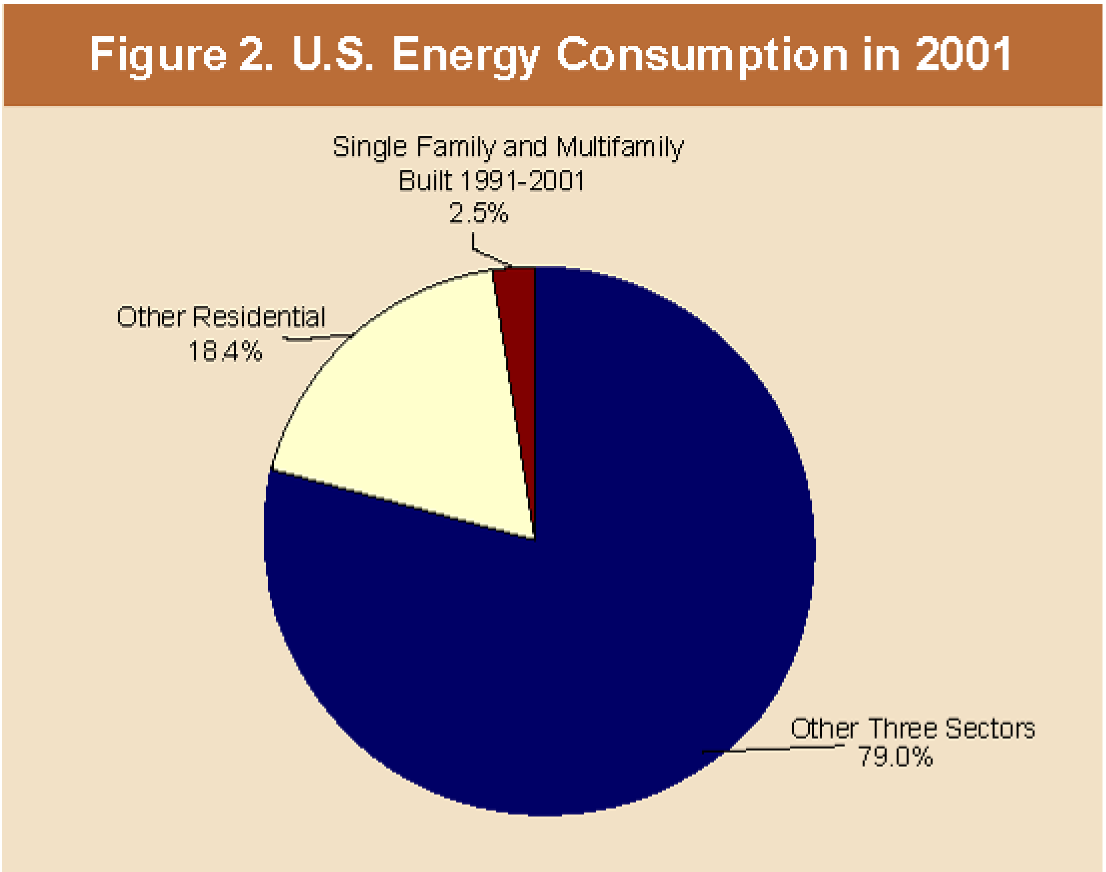
As a result, EIA usually reports total greenhouse gas emissions in MMT CO_2 equivalent, inflating metric tons of non-CO_2 gases to account for their greater impacts per ton. Even measured in MMT CO_2 equivalents, however, CO_2 accounted for 84 percent of U.S. greenhouse gas emissions in 2005.

EIA also typically breaks down U.S. energy consumption into four end-use categories: industry, transportation, residential, and commercial. Almost all residential greenhouse emissions are CO_2, and CO_2 emissions are strongly related to energy consumption. Thus, the residential sector accounts for 21-22 percent of both energy consumption and CO_2 emissions (Table 1). However, the residential sector generates very little greenhouse gases other than CO_2, and so accounts for only 18 percent of total greenhouse gas emissions measured in MMT CO_2 equivalents (Figure 1).

Figure 1. U.S. Total Greenhouse Gas Emissions in 2005

(MMT CO2 equivalent)





In the residential sector, CO_2 accounts for over 98 percent of greenhouse gas emissions (Table 2). 100 percent of the residential CO_2 emissions are energy-related. About 99 percent of residential methane emissions come from the relatively inefficient combustion of wood in fireplaces and woodstoves. 100 percent of residential nitrous oxide emissions result from some type of combustion—75 percent from combustion used to generate electricity. 100 percent of residential sulfur hexafluoride emissions are due to the substance escaping from electric utility transmission and distributions systems, where it is used as an electrical insulator. Thus, almost all residential greenhouse gas emissions are related to energy consumption in one way or another.

Note that EIA allocates some of the emissions from electric power generation to the residential sector. EIA estimates that the electric power sector accounted for about 40 percent of total CO_2 emissions in 2005, but allocates these emissions to the four primary end users based on electricity sales. This is quite significant and an important point to keep in mind. Without a share of the electric power industry's emissions, the residential sector would account for about 10 percent of CO_2 emissions, rather than 21 percent.

Individually, the impacts of the industrial, transportation, residential, commercial, and electric power sectors are each significant. Efforts to reduce greenhouse gas emissions are likely to be more effective if directed broadly across all sectors, rather than focused narrowly on one sector to the exclusion of others.

Life Cycle Assessment or Annual Consumption?
The previous section dealt with annual consumption. Some engineers, environmental advocates, and product manufacturers prefer instead to phrase the issue in terms of "life cycle

assessments.” A life cycle assessment follows a product from the beginning to the end of its life, analyzing the impact on the environment at each stage.

This may be a reasonable way to analyze some manufactured products, but for a product as complex and long-lived as a residential building a thorough life cycle assessment introduces many problems, and an attempt to solve all of them may not provide a clearer result than a more straightforward consumption analysis.

Aggregate data on energy consumption are published regularly and in a consistent fashion by EIA. EIA also conducts additional surveys and studies that enable researchers to analyze many of the data in more detail. Unlike the life cycle assessments based on a specific home in a particular location, the data collected and published by EIA are nationally representative and thus are generally more useful when trying to quantify environmental impacts for the entire U.S.

Moreover, energy consumption dominates the environmental impacts of a home after it has been built and is so closely related to greenhouse gas emissions, it often makes sense to concentrate on annual energy consumption when analyzing the post-construction phase of a home’s life cycle. See the sidebar on life cycle assessments for more details.

New Homes vs. Old

Another reason to focus on annual energy consumption in the residential sector is because a relatively small share of new housing is added to the existing stock in a given year. About 1.5 percent of the total housing inventory is new single family and multifamily construction. Even in 2005 when the housing starts reached a peak, new single family and multifamily construction still accounted for only 1.67 percent of the total inventory.

The EIA conducts several surveys of energy users. In the housing sector, the end-use survey is known as the RECS (for Residential Energy Consumption Survey). Although EIA’s use of the RECS to calculate total greenhouse gas emissions is relatively minor (for example, to estimate methane emissions from fireplaces), the survey is essential for estimating energy used by homes with different characteristics. And fundamentally, the energy consumption is strongly correlated with CO2 emission.

EIA converts different units of energy consumption into British thermal unit (Btu), which makes calculation and comparison easier. The numbers are rescaled slightly in Table 3 to match the residential energy consumption reported in the Annual Energy Review. [4] The most recent Residential Energy Consumption Survey in 2001 shows that the pre-1991 homes account for 81.56 percent of residential energy consumption (17.10% divided by 20.96%, in Table 3). Single family and multifamily units built in the decade before the survey was conducted (1991-2001) account for only 2.52 percent of total energy consumption in the U.S. This illustrates how important it is to focus on the existing stock of housing in addition to the new units being produced on the margin of each year. Even if each of the new homes built over the 1991-2001 period consumed zero energy, it would only have reduced total consumption in the U.S. by 2.52 percent. The same result could be achieved by improving the average efficiency of the pre-1991 homes by 14.7 percent.” [5]

Also note that, within the category of residential consumption, more than half of total residential energy consumption consists of losses that occur in generating electric power—that is, energy lost in producing and transmitting electricity, rather than energy actually used in residential structures. Most of the loss occurs at steam-electric power plants in the process of converting heat into mechanical energy to turn generators.

Hence there are two ways to reduce residential energy consumption and the resulting CO2 emissions. The first is to lower the energy consumed in the home itself, which will conserve not only the energy consumed at the residential site, but also (to the extent that the energy consumed is electrical) the energy that would have been required to generate the electricity.

The second is to make power plants more efficient and to reduce the energy lost in generation and transmission. Outside of replacing steam-electric plants with some other generation method, total elimination of this inefficiency is not possible. EIA estimates that electric power companies use about 3 Btu of other energy to generate 1 Btu of electricity and deliver it to the end users. So there seems to be considerable room for improvement. Also, greenhouse gas emissions could be reduced if it were possible to replace some current power generating facilities with alternate technology that did not burn fossil fuels. Any improvement in power generation would benefit not only the residential sector, but the other three end-use sectors as well.

HVAC vs. Other Uses

In addition to electricity, typical types of energy used in the residential sector include natural gas, fuel oil, kerosene, liquefied petroleum gases and wood. Major uses of energy in the residential sector can be grouped into space heating, air conditioning, water heating and running home appliances. Energy used on space heating and air conditioning is closely related to geographic location and characteristics of the unit, such as tightness of the thermal envelope and efficiency of the furnace.

New construction is more energy-efficient because of better insulation and HVAC equipment. Single family detached homes built in 1990-2001 on average used about 43,000 Btu per square foot of heated area per year, in contrast to 71,410 Btu for homes built in 1940-1949 and 63,260 Btu for homes built before 1940 (Table 4). Although the size of new homes has increased, the total energy used on heating and cooling has not, especially when newer homes are compared to homes built before 1940.

According to the 2001 Components of Inventory Change (CINCH) Report, the existing homes built before 1940 accounted for 19 percent of the housing stock, and had a comparatively high removal rate (Table 5). This does not imply that all new home buyers move out of pre-1940 structures, but when new home buyers move out of existing homes of whatever age, it frees those homes to be occupied by others. This “filtering” process continues until, at the margin, some homes can be retired. Table 5 suggests that this will often be pre-1940 homes which, despite their smaller average size, use more energy for heating and cooling than brand new homes do. Although it is desirable to make new homes more energy-efficient, it’s not desirable to this at a cost so high that it slows the rate at which pre-1940 homes are replaced, unless action is also taken to retrofit the older homes and bring them up to current standards.

Because HVAC equipment is typically installed when new homes are built, and the extent to which it’s used depends in part on insulation and other structural characteristics, builders and architects have some control over this aspect of energy consumption. However, owners of new custom homes clearly have input on the choice of heating equipment and many structural characteristics. Even in homes built anticipating a buyer, the builder builds homes with features that their customers desire and are willing to pay for.

Although influenced by customer preferences, the builder typically installs the HVAC equipment, insulation, windows, and other characteristics that impact the thermal envelope of a house. In this sense, builder decisions impact energy consumption.
However, household decisions made once the home is occupied (such as thermostat settings) also impact the amount of energy used for heating and cooling.

The Influence of Household Behavior

When it comes to energy used for other residential purposes (cooking, laundry, water heating, lighting, operating video and audio devices, etc.) the design and construction of the building are much less of a determinant of total consumption use. Instead, the occupants and their daily habits are much more significant.

Items such as kitchen appliances are often provided by builders, but the practice is not universal.

According to the Builder Practices Survey conducted by the National Association of Home Builders (NAHB) Research Center, only 46 percent of the new single family detached homes were equipped with refrigerators in 2005.

This section of the article uses the RECS data to look at electricity used for purposes other than space heating and cooling. Statistical techniques are used to separate the effects of a home's structural characteristics (such as is size and age) from the effects of number and types of appliances in the home, and the effects of household behavior.

Statistical testing showed virtually no relationship between non-spaceconditioning electricity use and most general housing characteristics, such as age of the structure or types of rooms present. The number of people living in the home do impact the non-HVAC electricity use, and to the extent that larger families live in larger homes, the size of the home also impacts non-HVAC electricity use. However, the consumption is related first and foremost to the number of people in the unit, and only secondarily to the unit's size.

The estimates of the statistical model show that non-HVAC electricity use tends to be higher where the price of electricity is lower, in homes with a larger number of occupants, more appliances, or larger or older appliances, and where the appliances and electronic devices are used more often. The technical results are shown in a separate appendix.

To help illustrate the results, Table 6 uses the model to estimate energy use for a base case. The base case is an owner-occupied single family detached home built after 1980 with a value of approximately $220,700. The household occupying this unit is white non-Hispanic, has an income of 44,700 in 2001 dollars, and consists of two adults and one child under age 13. The household pays 2.72 cents per 1,000 Btu for electricity and receives no help from the government's Low Income Home Energy Assistance Program. These numbers are based on typical values in the RECS data. The price of electricity is the average price in the RECS. House value and household income (for which the RECS groups the data into a limited number of discrete categories) are based on the median category observed in the data. Household characteristics are based on averages computed from the RECS data rounded to the nearest whole number.

The base case home contains a clothes washer and dryer, one refrigerator, one TV set, and one VCR or DVD player; but no ceiling fans, separate freezers, personal computers, fax machines or copiers, electric toasters, or electrically heated hot tubs, swimming pools, waterbeds, or large aquariums. The one refrigerator is 5 to 9 years old without side-by-side doors. These parameters are set to the lowest values that seem reasonable (an occupied home without a refrigerator or TV would be highly unusual), so that the impact of adding other appliances to a minimal-consumption configuration can be analyzed.

The base case further assumes that the household occupying the unit leaves four lights on 1-12 hours per day, no lights on longer than 12 hours, does not leave an outdoor light on all night, uses an electric stove less than once a day, uses a dishwasher less than once a day, uses the clothes washer less than twice a week, and does not use electricity to make coffee. Most of these are set to the lowest response categories in the survey, the objective again being to define a minimal consumption base case. The number of lights left on 1-12 hours is based on the average in the RECS data, rounded to the nearest whole number. This, combined with an assumption of no lights left on longer than 12 hours, still produces a relatively conservative consumption number.

The estimated non-HVAC electricity use for the base (or minimal consumption) case is 14,479 thousand Btu per year. From this starting point, the table shows the estimated impact on electricity consumption when an additional appliance or other electronic device is added. For example, adding one ceiling fan to the home increases electricity use by 454 thousand Btu (or 3.1 percent above the base case) per year and adding a hot tub increases electricity use by 7,361 thousand Btu (50.8 percent).

The table also shows the impacts of changes in household behavior. For instance, if the household leaves outdoor lights on all night, annual electricity consumption increases by 2,777 thousand Btu (19.2 percent above the base case). If the household uses the dishwasher daily, electricity use increases by 5,943 thousand Btu (41.0 percent).

The table is organized so that the first seven changes to the base model consist of items like ceiling fans that would often be installed by the builder in a new home. Changes 8-31 capture items that are more purely a function of household decisions. The number of TV sets, DVDs, VCRs, and personal computers in the home are grouped in the latter category. Although a builder may build a home with a media room, the occupying households decide ultimately how to use the room, and how many TV sets and DVD players they use. However, the table shows the impact of each factor on electricity consumption separately, so readers can study the impact of each electronic device individually if they want to.

To illustrate the cumulative impact that features provided by builders can have on energy consumption, the table also shows what happens when all of features 2 though 6 are added to the home. [6] The effect of these items is to increase annual energy consumption over the base case by 19,552 thousand Btu (or 135.0 percent).

In comparison, the many factors over which builders have virtually no control (the number of DVD players, how long lights are left on, etc.) can increase annual electricity consumption by as much as 42,127 thousand Btu (290.1 percent).

Because consumption patterns that are purely attributable to household behavior (such as leaving lights on or the frequency of dishwasher use) has such a strong impact on total electricity use, a policy to reduce residential greenhouse emissions is likely to be more effective if it focuses not only on home features that builders can control, but also on consumer education and encouraging conservation practices among home owners.

Conclusions

- Residential energy consumption contributes to greenhouse gas emissions primarily through CO_2 emissions.

- More than half of the energy consumption and CO_2 emissions attributable to the residential sector is the result of energy "lost" in the generation and transmission of electricity.

- New homes (those built in the last ten years) account for about 12 percent of residential energy consumption.

- Per square foot, new homes consume less than two-thirds the energy of older homes for the core HVAC uses controllable by builders.

- Behavior of the occupants has a larger impact on non-HVAC energy consumption than those items under the control of the builder.

- More stringent energy conservation requirements for new homes can have a reverse effect of retarding filtering and keeping people in older, less energy-efficient homes.

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Footnotes

[1] CO2 is not only the most significant greenhouse gas, in terms of total emissions, it's also the greenhouse gas for which emissions are easiest to estimate. EIA has an elaborate system in place for collecting information from producers, importers, distributors, and sellers of various fuels to keep track of how much is consumed. Some of the information is collected as frequently as every week. EIA also generally knows how many carbon atoms each fuel contains. When the fuels are consumed each carbon atom combines with two oxygen atoms. CO2 emissions thus emerge as an easy calculation that is not impacted by changes in technology (unlike methane emissions, for instance, which are impacted by the types of catalytic converters in automobiles).

[2] The IPCC was created by the United Nations (UN) Environment Programme and World Meteorological Organization (WMO) in 1988 and is open to any country belonging to either the UN or WMO. So far, the IPCC has issued three reports on assessing climate change, and is planning a fourth for 2007. In its tabulations of energy use and greenhouse gas emissions, EIA often reports that it is following protocols established by the IPCC.

[3] In general, the global warming potentials for each gas change when a new IPCC assessment is issued. EIA asserts that the last set of changes in global warming potentials did not have a substantive impact on its estimates of greenhouse gas emissions.

[4] Total residential consumption in the RECS is a little over 21,000 trillion BTU, compared to about 20,228 trillion BTU in the Annual Energy Review, so the effect of the rescaling is minor.

[5] If new homes built between 1991 and 2001 consumed zero energy, it would reduce total energy consumption by 2,429 trillions of Btu. If the energy-efficiency of pre-1991 homes is improved so that the same amount energy is saved, the calculation is 2,429/16498=14.7 percent.

[6] The effect of a heated swimming pool is excluded. Although they have a very large impact on electricity consumption when present, heated pools are comparatively rare in single family homes.

Residential Greenhouse Gas Emissions (Life Cycle Assessments)

By Paul Emrath, PhD and Helen Fei Liu, PhD.

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A life cycle assessment follows a product from the beginning to the end of its life, analyzing the impact on the environment at each stage. This may be a reasonable way to analyze some manufactured products, but for a product as complex and long-lived as a residential building a thorough life cycle assessment introduces many problems, and an attempt to solve all of them may not provide a clearer result than a more straightforward consumption analysis.

One component of a life cycle assessment consists of impacts that result from turning raw materials into a final product. This is called a "cradle-to-gate" analysis and has become common in many manufacturing industries.

A typical way to analyze environmental impacts during this part of the life cycle is to estimate the amount of "embodied energy" in a product. Embodied energy includes all the energy used to extract raw materials and turn them into a finished good, including transporting and installing the products.

The U.S. government does not at present provide estimates of embodied energy, and hasn't for some time. The calculations involved can be quite difficult, even for top experts analyzing a single building product. Engineering computer programs now exist that calculate embodied energy for an entire residential building, but the models produce results that are difficult to replicate or generalize, as many of the inputs are quite specific to a particular house and job site (e.g., distances from manufacturers).

For some purposes, rough or incomplete embodied energy estimates may be adequate, even if they don't lend themselves to being combined with annual consumption numbers to produce a life cycle assessment. Manufacturers interested in reducing embodied energy in a particular building material, for example, need only be able to estimate the embodied energy for that material. Similarly, builders can make informed environmental decisions about materials with fairly rough embodied energy estimates for relevant choices (e.g., fiberglass and expanded polystyrene insulation) if the differences are very large.

Estimates of embodied energy are sometimes but not always turned into estimates of greenhouse gas emissions. This is most likely to be done for a single, relatively simple product (e.g., kiln-dried softwood lumber), where the manufacturing processes and energy sources used are relatively well understood.

Other estimates required for a thorough life cycle assessment of a home include estimates of environmental impacts resulting from maintenance and replacements over the home's lifetime, as well as of the impacts that will occur at the end of the home's life. This in turn means that both embodied energy and durability estimates are needed for a large number of building components. The energy embodied in all future removals and replacements, and the time when these events will occur, needs to be taken into account. The uncertainties involved in estimating both durability and embodied energy for a large number of components (as well as the products and techniques that will be used to replace them at the end of their usually very long service lives) make this part of the assessment very difficult.

A major uncertainty is the expected life of the house itself. Residential removal rates are notoriously difficult to estimate, especially since the U.S. Census Bureau stopped collecting data on residential demolition permits (a change NAHB opposed at the time and has tried unsuccessfully to reverse on several occasions). Partly for this reason, manufacturers of products used in home building seldom analyze environmental impacts for their products after the "cradle-to-gate" stage (that is, after the time they are installed in a home).

In addition, the available evidence suggests that environmental impacts associated with maintenance and demolition are small compared to annual energy consumption. A 2005 Corrim study, for example, produced the following estimates for a particular type of wood frame house in Minneapolis with an estimated life span of 75 years:i

CO_2 from maintenance over the life of the house: 3,468 kg
CO_2 from removal at the end of the home's life: 435 kg
CO_2 from heating and cooling over the life of the house: 388,000 kg

Thus, the estimated emissions associated with maintenance and removal barely add to one percent of the emissions associated with heating and cooling. An effort to extend the analysis to include energy consumption beyond heating and cooling (which would capture a substantial amount of green house gases generated by electricity production) seems clearly worthwhile. The value of refining or extending the residential maintenance and demolition impact estimates is less obvious.

In summary, the environmental impacts of a home can be broadly separated into construction or "cradle to gate" impacts (which are exceptionally hard to estimate for a product as complex as a home) and use/removal impacts—which extend over the life of the home, are dominated by annual energy consumption, and include numerous other impacts that are simultaneously quite small and quite difficult to estimate. For many purposes it makes sense to keep the two sets of impacts separate

[i] Paul Winistorfer, Zhangjing Chen, Bruce Lippke, and Nicole Stevens, "Energy Consumption and Greenhouse Gas Emissions Related to the Use, Maintenance, and Disposal of a Residential Structure," Wood *and Fiber Science,* 37 Corrim Special Issue, 2005, pp. 128–139.